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REPORT NO. R-1287

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FACTORS AFFECTING SMALL ARMS TRACER BURNING

BY

R. S. Shulman

PROJECT TSI-46

PITMAN-DUNN LABORATORIES
FRANKFORD ARSENAL
PHILADELPHIA, PA.
September 1955

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REPORT R-1287

FACTORS AFFECTING SMALL ARMS TRACER BURNING

Project TS1-46

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ACKNOWLEDGMENT

Acknowledgment is due Mr. Thomas Stevenson, Research Advisor, who initiated and guided this project through its early stages. His suggestions and comments were of immeasurable value in the execution of this work.

OBJECT

(1) To obtain data denoting the effect of angular velocity upon the burning rates of standard small arms tracer projectiles;

(2) To study the influence of angular velocity upon the light intensity of these standard tracer projectiles; and

(3) To derive sufficient data and a technique to study the effect of geometry and cavity upon the burning rates and light intensities of spinning tracer projectiles.

SUMMARY

Burning time vs rpm curves have been extended to 90,000 rpm for several standard tracer projectiles. Graphs of these are shown in Figures 5 and 6. The influence of angular spin and igniter compositions upon the light output of various tracers is noted. Data obtained indicate a relationship between the cavities formed in burned-out tracer bodies and the rotational velocities used. The effect of the size of these cavities upon the candlepower values of these tracers is described.

AUTHORIZATION

OCM 33344, 22 Jan 1952

INTRODUCTION

It has been recognized for many years that tracer projectiles burn for much shorter periods of time in flight than when burned statically. For example, caliber .50 M1 tracer bullets burn statically approximately 13 seconds, and less than 6 seconds in flight.

The greatest influence, by far, upon the behavior of burning tracers was recognized to be their spin in flight. Early data obtained at relatively low angular velocities indicated that tracer burning rates tend to decrease asymptotically with increased spin and that a rotational speed of approximately 100,000 rpm in the laboratory would be adequate for simulating flight burning times of small arms tracers.

Rotational speeds approaching 40,000 rpm were obtained by various researchers who used geared motors. Although this range of angular velocity gave some idea as to the effect of spin upon the candlepower-time behavior of tracer bullets, it was much too low to supply adequate data for small arms tracer ammunition which has angular velocities ranging from approximately 130,000 to 180,000 rpm. A decrease in candlepower values was noted by various investigators, but they were unable to delve deeper into this phenomenon since they were limited by the scope of their apparatus.

In attempts to further duplicate flight conditions, some investigators used directed air flows about the burning tracers. In addition to angular spin and air flow, other factors exist that may also affect candlepower-time characteristics of tracers to a greater or lesser degree. The effects of lowered air pressure at the base of projectiles in flight, heat transference differences existing between free-spinning bullets in flight and those restricted by a spinning device, varying methods of ignition, and general behavior of projectiles at rotational speeds of 130,000 rpm or more, may be substantial collectively, may nullify one another, or may have little influence in altering data as compiled in laboratory tests.

The early methods of ignition by means of hot wires and electric primers were replaced by a sparking device which ignited a spark-sensitive mixture that had been placed upon the igniter.

In the work performed at Frankford Arsenal the use of a simulated air flow about the burning tracers was found to be impractical with the design and operation of the bullet spinner. A directed air flow, if used, would have cooled the core of the rotor rather than the bullet itself. It was found necessary to postpone a decision as to the necessity for and importance of an air flow until laboratory data could be evaluated with data obtained in field tests.

Subsequent results obtained at Aberdeen Proving Ground show that the absence of air flow not only is not critical but, in addition, the importance of its use in small arms tracer studies is questionable. The family of curves shown in this report would be modified very little, if at all, had a practicable air flow been incorporated into the apparatus.

Although the highest rotational speed used in this work was 90,000 rpm, higher speeds are considered possible with the present apparatus. It had been previously decided that a limiting speed of 90,000 rpm would be placed upon these tests as a safety measure should the results obtained indicate the trend of data at higher rotational speeds.

APPARATUS AND ITS OPERATION

Beams and Pickels of the University of Virginia* obtained high rotational speeds by means of small air turbines. The principles they developed were employed in the air turbines described in this report. However, many modifications were made necessary by the heavy rotors used and the difficulty of attaining high speeds with them.

The total weight of the rotor, stator, and stator cup, which are the vital components of the turbine, is less than six pounds. Additional bulk was added to improve safety (Figures 1, 2, and 3).

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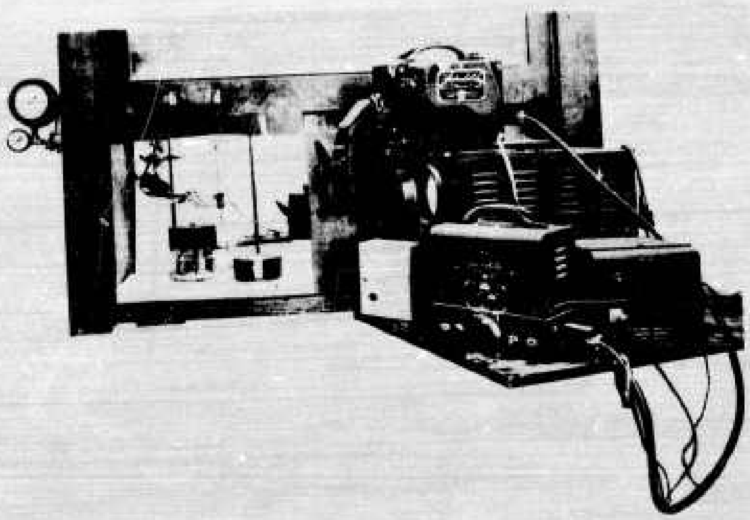

Figure 1. Candlepower-time apparatus

* "Production of High Rotational Speeds," Review of Scientific Instruments, Vol 6, Oct 1935

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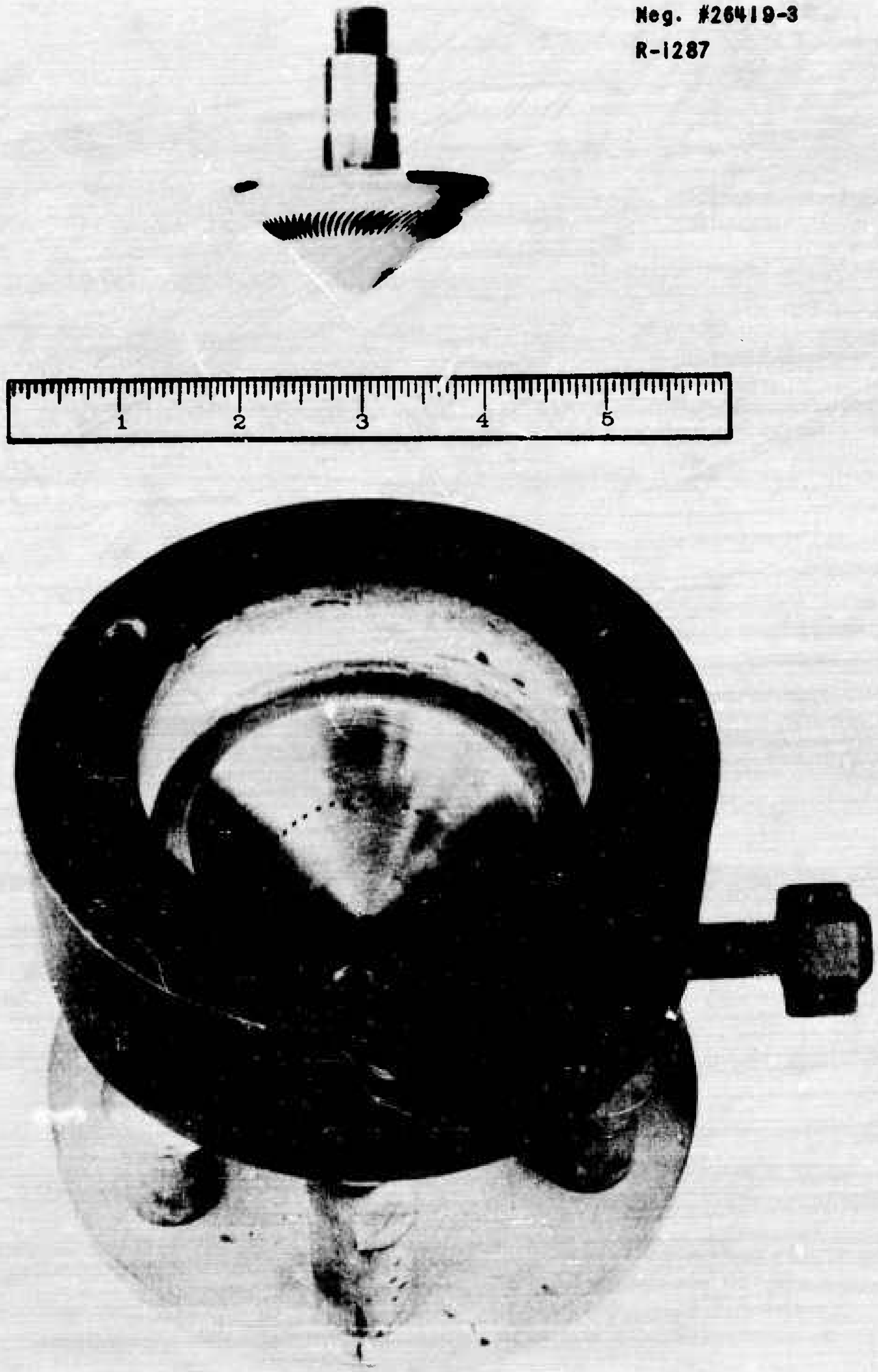

Figure 2. Bullet spinner

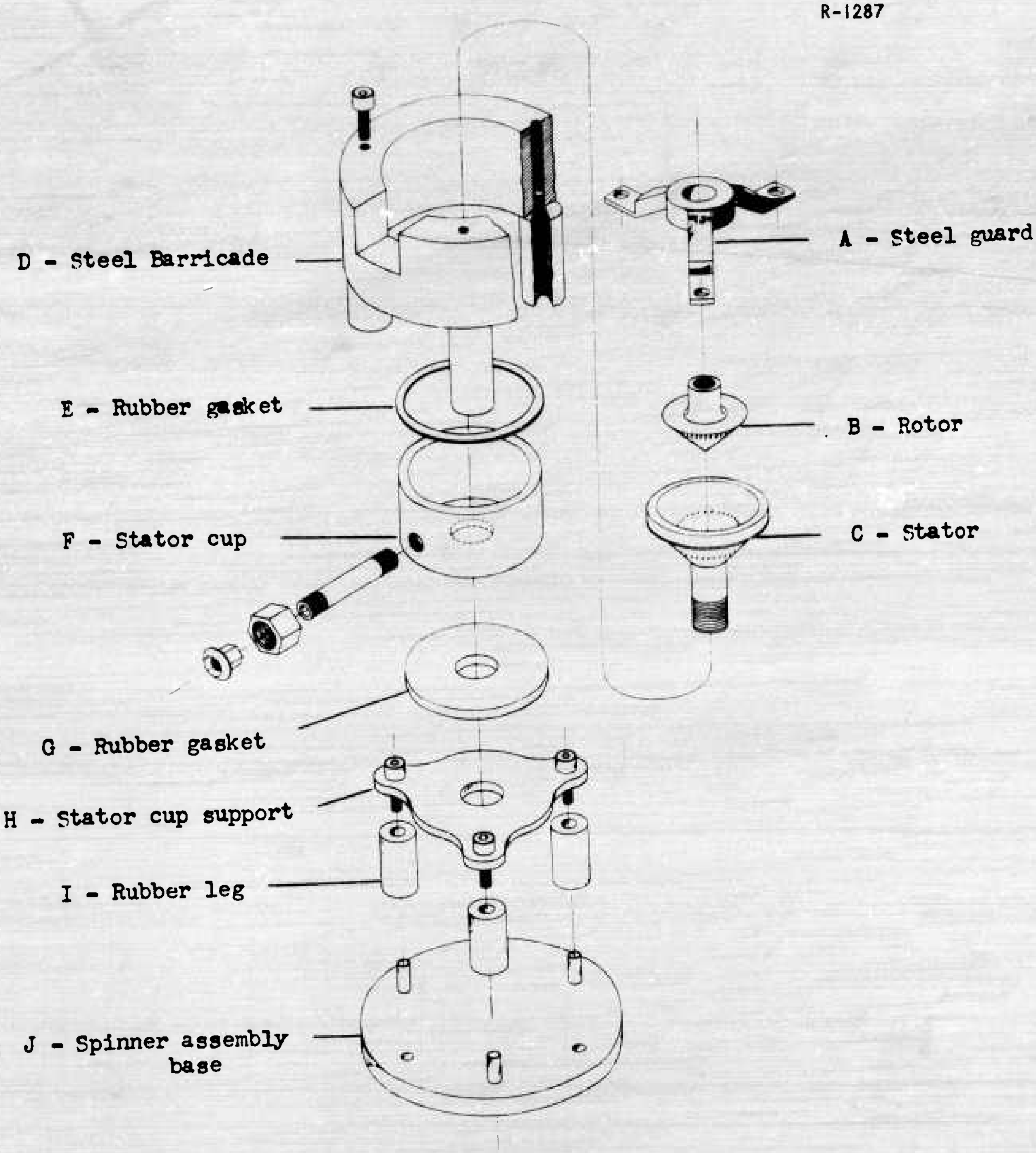

Figure 3. Exploded view of bullet spinner assembly

The rotors are made of steel while the stators are fashioned out of brass. The first rotor made weighs 1 1/5 pounds, has a 3 1/4 inch diameter and 32 flutes. Its calculated bursting speed is 115,000 rpm. The second rotor weighs 10 1/2 ounces, has a 2 1/2 inch diameter, 48 flutes, and a calculated bursting speed of 134,000 rpm. The third rotor, with which most of these studies were made, is identical to the second except that it has 70 flutes.

The stators differ in number and size of port holes. These holes vary from 16 to 40 in number and from 1/32 to 1/16 inch in diameter.

As work progressed, the limitations of the turbine necessitated changes in rotor and stator design and changes in safety procedure.

Sets of rotors and stators were calibrated by means of a stroboscope. For each combination thereafter, when a given speed was desired, the graph of these values (Figure 4) gave the air pressure to be used. The first rotor and first stator made reached a speed of 54,000 rpm at 50 psi, while the last set manufactured reached a speed of 90,000 rpm at 41 psi.

These calibration curves indicate the importance of slight modifications in stator and rotor design. In addition to altering the number and size of the flutes and stator holes, increased efficiency could also be obtained by modifying the angles of the rotor and stator and by changing the dimensions of the stabilizing air vent of the stator to meet the requirements of the rotor being used. The necessity for any of these further modifications was obviated by the attainment of sufficiently high speeds at relatively low air pressures.

The tracer bullets were inserted in the core of the rotor and ignited after the desired rotational speed was reached. Ignition was accomplished by means of a sparking needle attached to a Tesla coil. A release mechanism, activated by a solenoid, removed the needle from its position above the tracer after it had ignited a trace of spark-sensitive PbO_2-Zr mixture applied to the igniter surface. A slight dampening of this mixture with a drop of a volatile liquid, such as methyl alcohol, prevented its loss during the spinning of the bullet.

The light given off by the burning tracer was picked up by a photo-electric cell and generated a voltage across a high resistance. This was impressed on the input terminals of an oscilloscope. The magnitude of the deflection of the beam on the oscilloscope screen was directly proportional to the light fluctuations of the burning tracers. The movement of the beam on the screen was recorded on film, the duration of burning being measured by means of an electronic timer which imposed a periodic imprint upon the film. The light intensities recorded on film were evaluated against a standard lamp (Appendix A).

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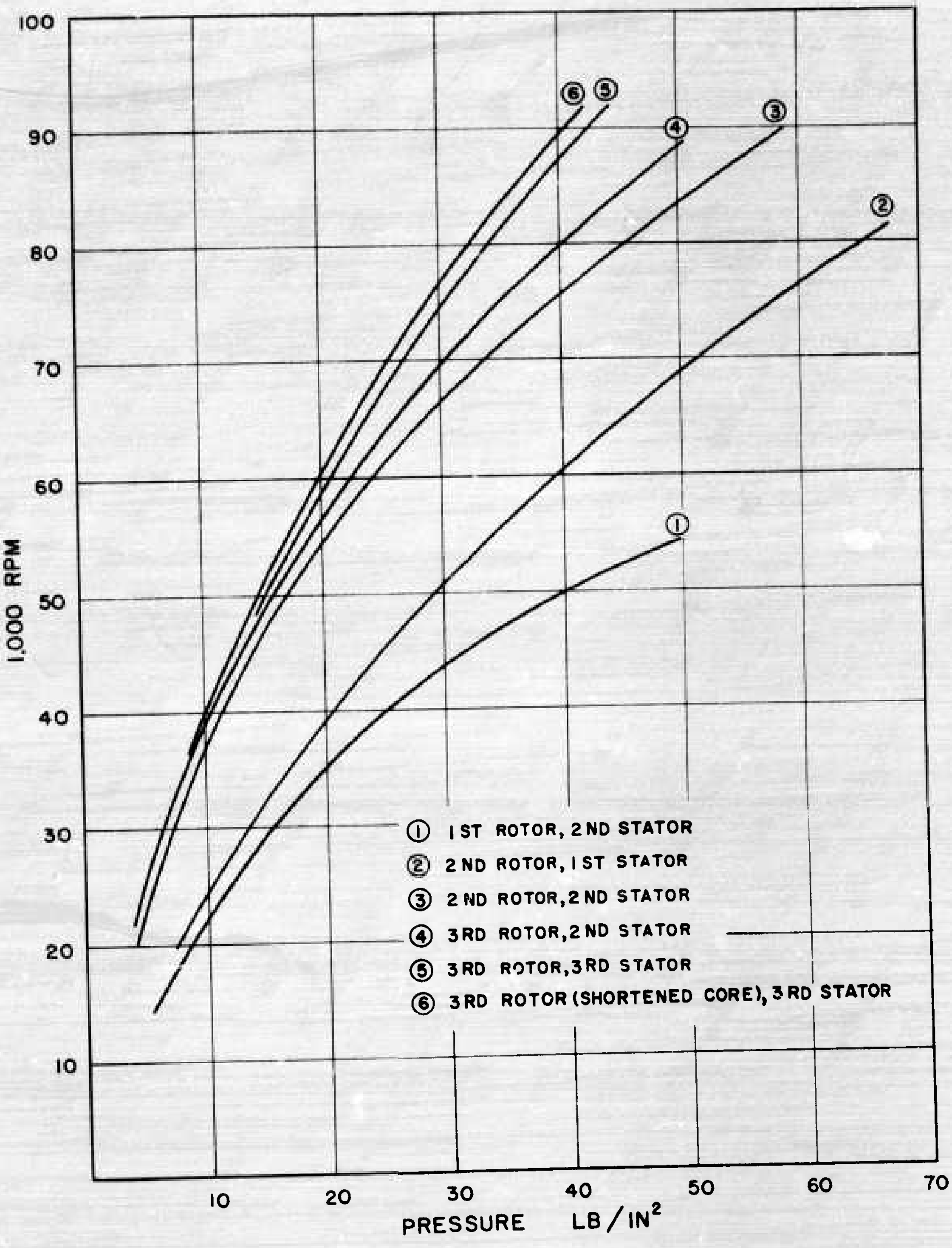

Figure 4. Calibration curves for various combinations of rotors and stators

In order to obtain burning time vs rpm curves that are representative of each type of tracer bullet, a minimum of ten tracers of each type was ignited at each increment of angular speed. Since the rotors used are unstable at speeds under 20,000 rpm, the data obtained are for angular velocities of 30,000 to 90,000 rpm.

SAFETY

The combination of high rotational speeds and burning tracers presented a safety problem. Because it was not known how each type of tracer would react under the shock of ignition while rotating at high speeds, or how the heat evolved would affect the strength of the rotor, adequate safety measures had to be incorporated into the apparatus.

The behavior and individual peculiarities of the steel rotors at high speeds were unknown factors. Their operation had to be considered hazardous and unpredictable at all times.

Potentially, a number of occurrences was possible. The explosion of a rotor, which was most feared, did not take place, but the following incidents proved the necessity for taking every precaution.

(1) Many projectiles detonated while rotating at high speeds, spraying particles of their jackets in the vicinity of the turbine. This appears to have been due to inadequate heat transference from the walls of the bullet jackets. It was found that, if the bullets were not permitted to protrude more than 3/8 inch beyond the core of the rotor, this tendency for jacket disintegration decreased substantially.

(2) In several instances the stress of ignition caused rotors to become unstable. This sudden instability caused either the ejection of the bullet from the core of the rotor or a violent tendency on the part of the rotor to leap out of the stator. The maintenance of stability in the rotors at all rotational velocities was a difficult problem. Many factors contribute to the stability of rotors, not all of which were fully explored. Sometimes the difference between stability and instability was so slight that a little increase in speed or a minute difference in bullet weight converted the rotor from a stable to an unstable state. In one instance, after ignition, a caliber .50 M1 tracer detonated while rotating at 75,000 rpm. The upper half of the barricade was not in position and the rotor left the stator, throwing the bullet out. The rotor landed nearby and continued to spin for almost 30 seconds. It was damaged. With the upper half of the barricade in position, an ejected bullet would be trapped

momentarily before being thrown clear, possibly resulting in damage to the rotor. Subsequent changes in rotor and stator design led to stable and satisfactory function.

(3) The rotor itself, conceivably, might explode under the stresses applied to it. To avoid this occurrence, calculations were made of the bursting speed of each rotor used and a limit was placed on its operating speed. The formula used to calculate bursting speeds is given in Appendix B.

The strongest available steel (174 PH stainless) was used in the manufacture of these rotors and they were X-rayed for the detection of any possible flaws before being placed in use. The continual heat treatments given to the cores of these rotors by the intense heat developed by the burning tracers (in excess of 1000° F) may contribute to their weakening, but thus far, none of the rotors displays any kind of defect.

A barricade of one inch thick steel inclosed the stator and rotor. A slit in the upper half of this barricade, directed toward the photocell, permitted the measurement of candlepower. As work progressed and the limitations of the turbine were better known, a steel guard was substituted for the upper half of the barricade in order to facilitate tests and, at the same time, prevent the rotor from leaping out of the stator.

The air turbine was inclosed behind a quarter inch thick steel door. All controls were outside this door.

RESULTS

The time-rpm curves for caliber .50 M1, M10, M17, and M20; caliber .45 M26; and caliber .30 M25 tracer bullets are complete for rotational speeds up to and including 90,000 rpm (Figures 5 and 6). Table I gives tracer and igniter charging data for all bullets used in this work.

Results obtained by firing these standard tracers at Aberdeen Proving Ground tend to corroborate, to a marked degree, the results obtained in laboratory work. The time-rpm data obtained at Aberdeen Proving Ground are incorporated in Figures 5 and 6. The slopes of these curves seem to permit the prediction of intermediate data at rotational speeds of 90,000 to 130,000 rpm with little likelihood of any appreciable error.

The influence of increasing spin upon the candlepower of tracers is not clear-cut. Conclusions should not yet be drawn from the data thus far compiled since the factors involved, which determine light intensity, are varied and complex. In some instances intensity increased with an increase in rotational velocity while in other cases there

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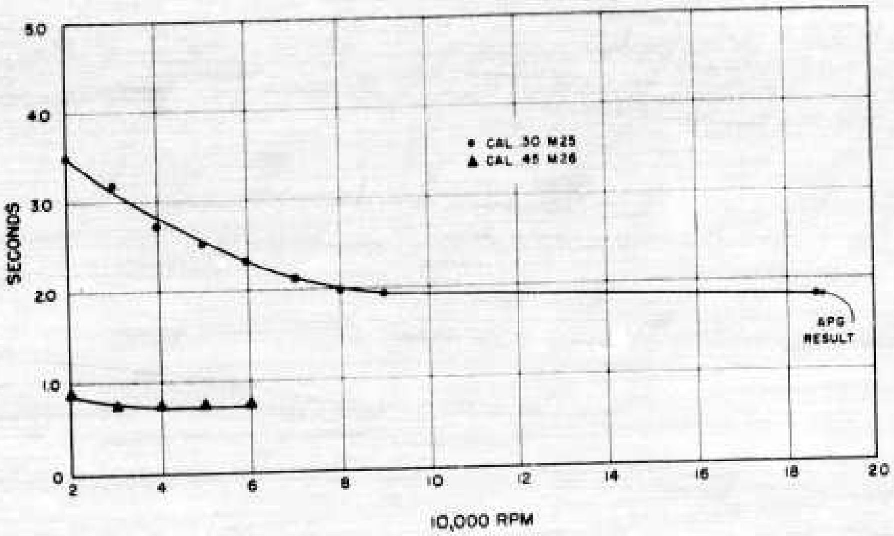

Figure 5. Effect of spin upon trace duration of small arms tracer ammunition

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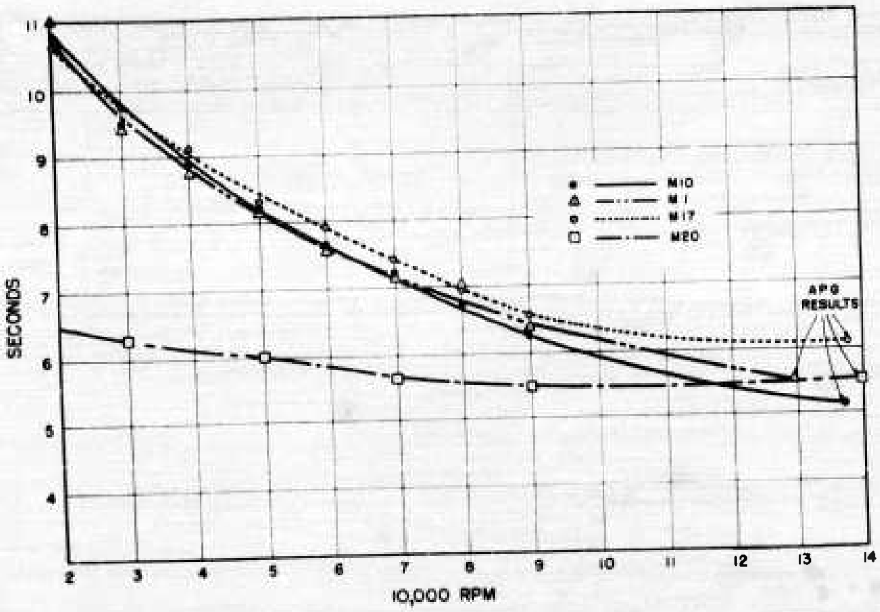

Figure 6. Effect of spin upon trace duration of small arms tracer ammunition

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Table I. Tracer and Igniter Data

COMPONENT			1ST CHARGE			2ND CHARGE			3RD CHARGE				RECOMPRESSION
CALIBER	CARTRIDGE	TYPE	COMPOSITION	WEIGHT (GRAINS)	COMPRESSION (LBS./SQ.IN.)	COMPOSITION	WEIGHT (GRAINS)	COMPRESSION LBS./SQ.IN.	COMPOSITION	WEIGHT (GRAINS)	COMPRESSION* (LBS/SQ IN)	COMPRESSION* (LBS/SQ IN)	COMPRESSION (LBS/SQ IN)
50	M 1	TRACER	TRACER R-284	40 APPROX.	100,000 APPROX	TRACER R-256	15 APPROX.	NONE	IGNITER I-276	10-11	100,000 APPROX.	100,000 APPROX	100,000 APPROX.
	M 10	TRACER	TRACER R-256	40 APPROX.	100,000 APPROX	TRACER R-256	15 APPROX	NONE	IGNITER I-194	10-11	100,000 APPROX.	100,000 APPROX	100,000 APPROX
	M 17	TRACER	TRACER R-321	40 APPROX.	100,000 APPROX	TRACER R-256	15 APPROX	NONE	IGNITER I-508	10-11	100,000 APPROX.	100,000 APPROX	100,000 APPROX
	M 20	APIT	TRACER R-321	7 APPROX.	115,000 APPROX.	TRACER R-256	2 APPROX	NONE	IGNITER I-508	3	115,000 APPROX.	115,000 APPROX	NONE
45	M 26	TRACER	TRACER R-256	2.5 APPROX.	NONE	IGNITER I-276	2.5	32,000 APPROX					
30	M 25	TRACER	TRACER R-284	6.5 APPROX.	84,000 APPROX.	IGNITER I-280	0.35	18,000 APPROX	IGNITER I-136	1	90,000 APPROX	NONE	NONE

IGNITER	MAGNESIUM "B"	BaO_2	TOLUIDINE RED	CALCIUM RESINATE	ZINC STEARATE	SrO_2	PbO_2	ZIRCONIUM	GUM ARABIC	ATOMIZED MAGNESIUM	PARLON	$Sr(NO_3)_2$	$KClO_4$	POLYVINYL CHLORIDE	SrC_2O_4
I-194	6			9.4		84.6									
I-276	15	63	1		1										
I-508		IGNITER I-276 + 6% PARLON													
PbO_2-Zr							68	22.5	9.5						
TRACER															
R-256				8.3		26.7				26.7		33.3			5
R-257				4						28		40.	20		8
R-284										28		55		17	
R-321										26	6	62		16	

*First and second strokes of punch

was an initial increase and then a subsequent decrease in intensity (Figures 7 through 11). It is evident from an examination of the films that the candlepower values do not follow the same pattern for each tracer. This, of course, is due to the individual characteristics of each tracer composition.

It appears possible from the results of this work that alterations in standard composition formulation of both igniter and tracer mixtures, to bring out the desired characteristics while suppressing the undesirable ones, may lead to tracers whose candlepower is unaffected by angular velocity, providing other factors, such as slag cavity size and slag density, remain constant.

Ordinarily, one might assume that a given amount of tracer composition, when loaded into a bullet, has a known total candlepower content. Furthermore, if rotating this bullet reduces burning time, average candlepower values per second of burning time should increase. However, as spin increases it becomes more difficult for burning particles to escape. Although the slag cavity tends to increase in diameter as spin increases, the loss in weight undergone by tracers tends to decrease, demonstrating that it becomes progressively more difficult for burning particles to escape. These particles are thrown to the walls of the projectile and lose much of their energy.

Measurements of cavities produced at various rotational speeds and weighings of burned-out projectiles (Table II) show the trend toward a slag of greater density at higher speeds. Losses in weight and slag cavity dimensions were not recorded for caliber .45 M26 and caliber .30 M25 tracers, since the data obtained for the caliber .50 tracers were considered sufficient to illustrate this behavior.

Table II. Effect of Spin upon Slag Characteristics of Various Types of Small Arms Tracer Ammunition

Tracer	rpm	Original Charge Wt (gr)	Avg Wt Loss (gr)	Avg Loss (%)	Slag Cavity Dimensions After Burning (64th in.)	Cavity Type
M20	30,000	12	4.4	37.4	3 to 4	Oval and irregular
M20	50,000	12	4.6	38.4	3 to 4	Oval and irregular
M20	70,000	12	4.6	38.4	4	Oval
M20	90,000	12	4.4	37.4	4	Oval
M1	30,000	65	32.7	50.4	12 to 13	Round and irregular
M1	50,000	65	32.4	49.8	12 to 14	Round
M1	70,000	65	30.8	47.5	13	Round
M1	90,000	65	30.8	47.5	14	Round
M10	30,000	65	31.6	48.6	12	Irregular
M10	50,000	65	29.3	45.1	12	Irregular
M10	70,000	65	27.8	42.8	12	Round and irregular
M10	90,000	65	27.6	42.5	12	Round and irregular
M17	30,000	65	30.4	46.6	10 to 12	Round and irregular
M17	50,000	65	27.5	42.3	11 to 13	Round and irregular
M17	70,000	65	28.5	43.8	13 to 13.5	Round and regular
M17	90,000	65	28.4	43.7	13 to 14	Round and regular

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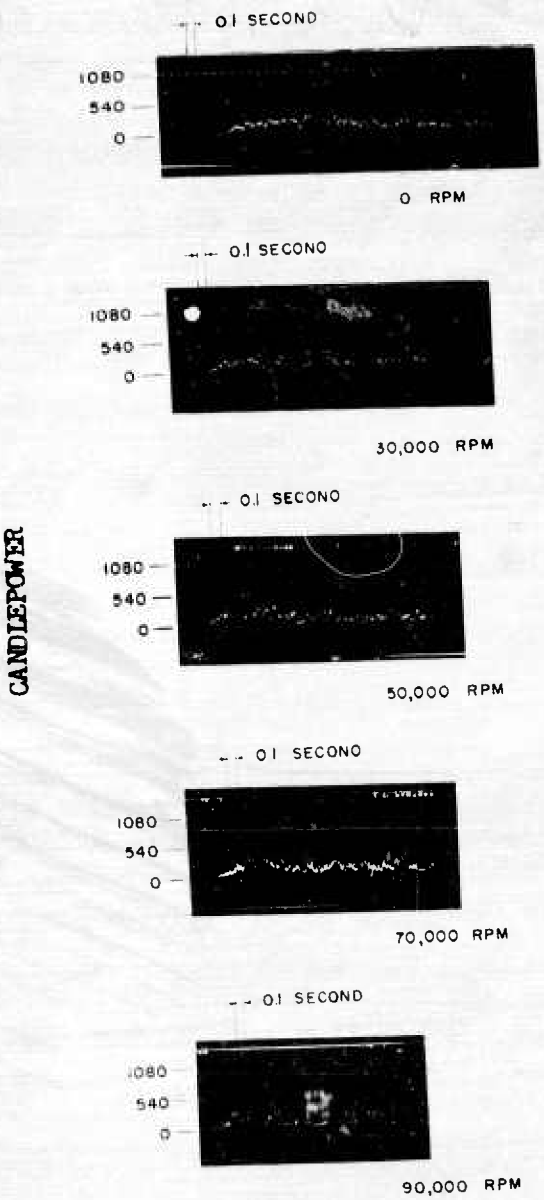

Figure 7. Effect of spin upon candlepower-time behavior of caliber .30 M25 tracer bullets

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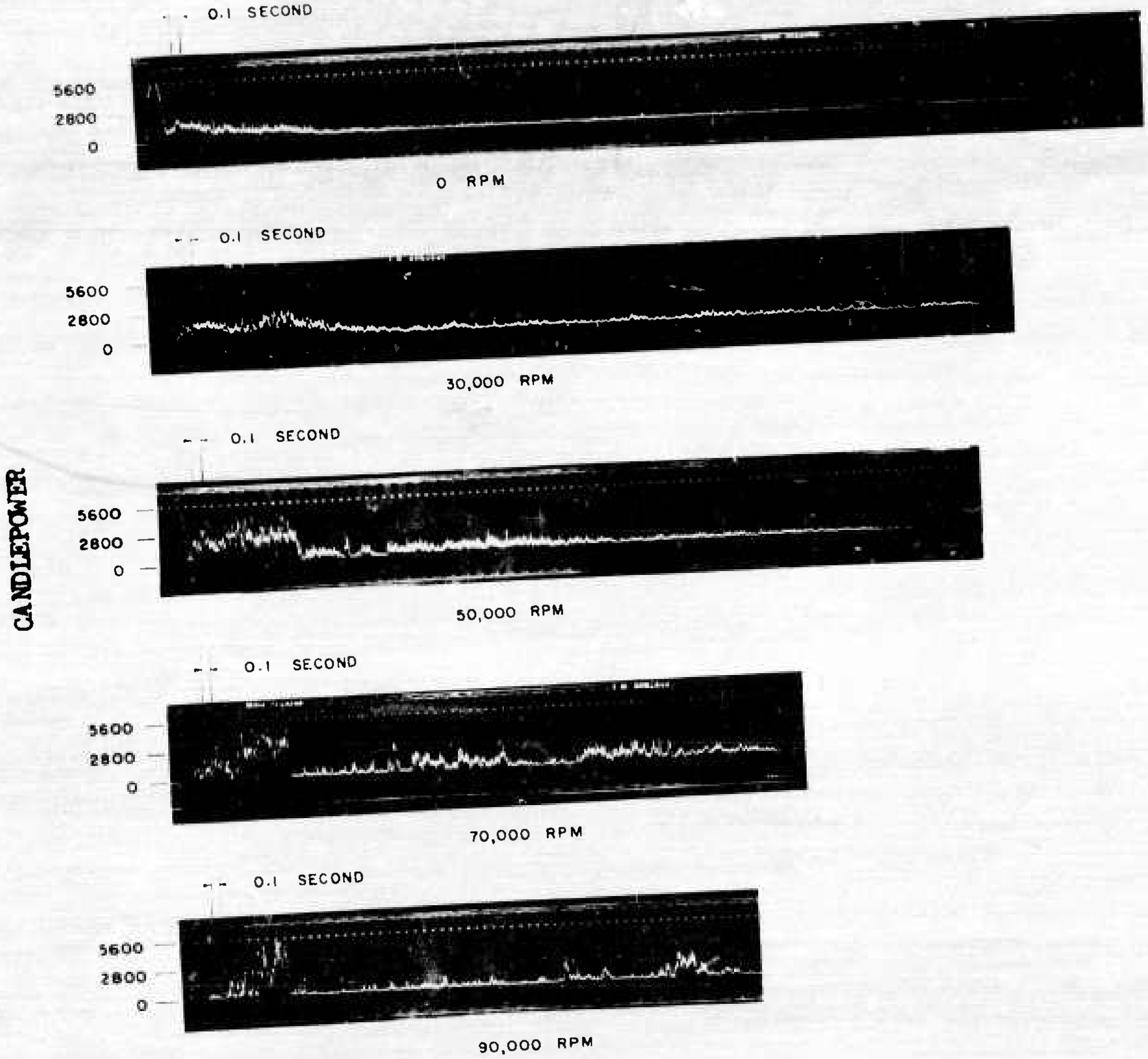

Figure 8. Effect of spin upon candlepower-time behavior of caliber .50 MI tracer bullets

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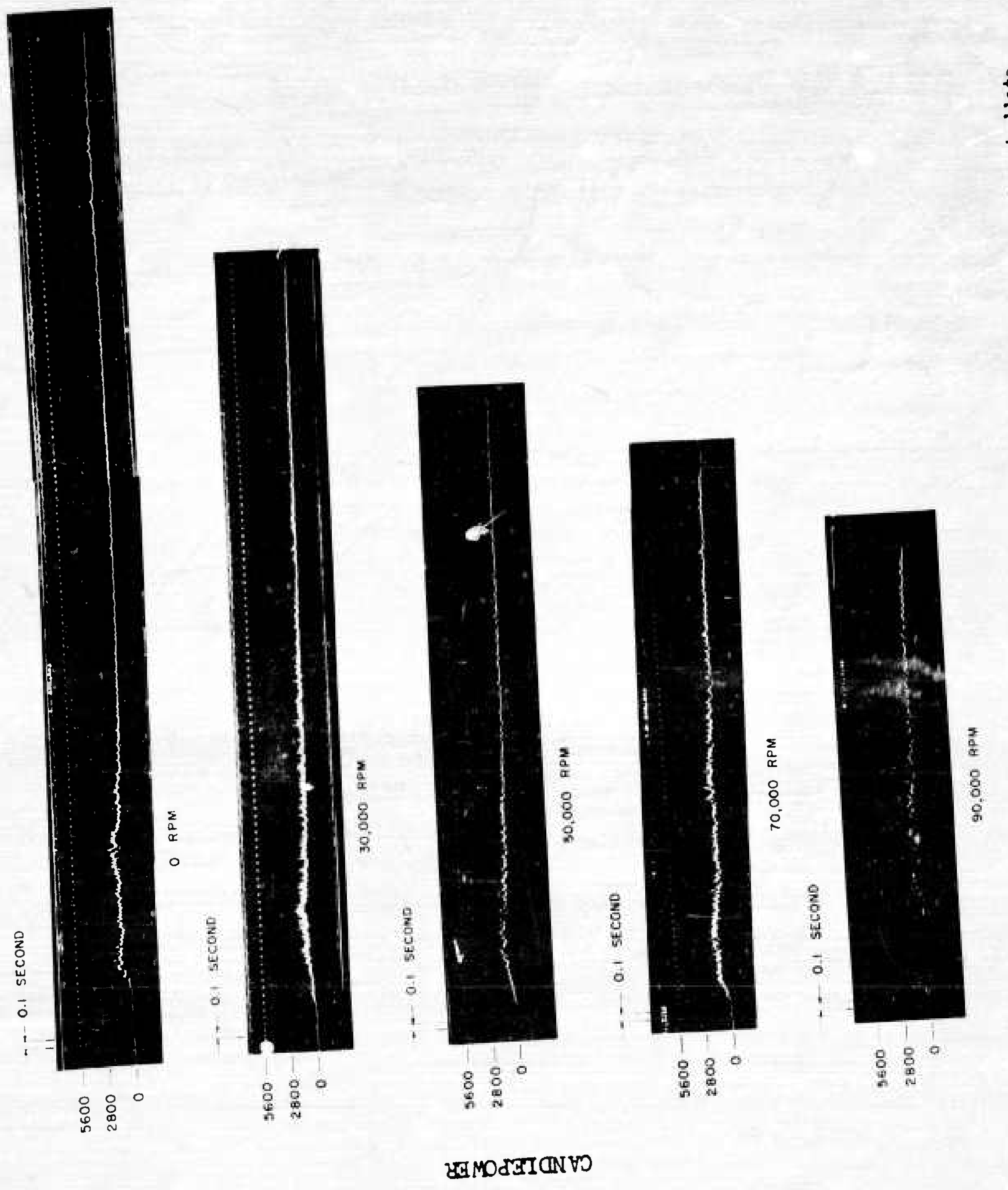

Figure 9. Effect of spin upon candlepower-time behavior of caliber .50 M10 tracer bullets

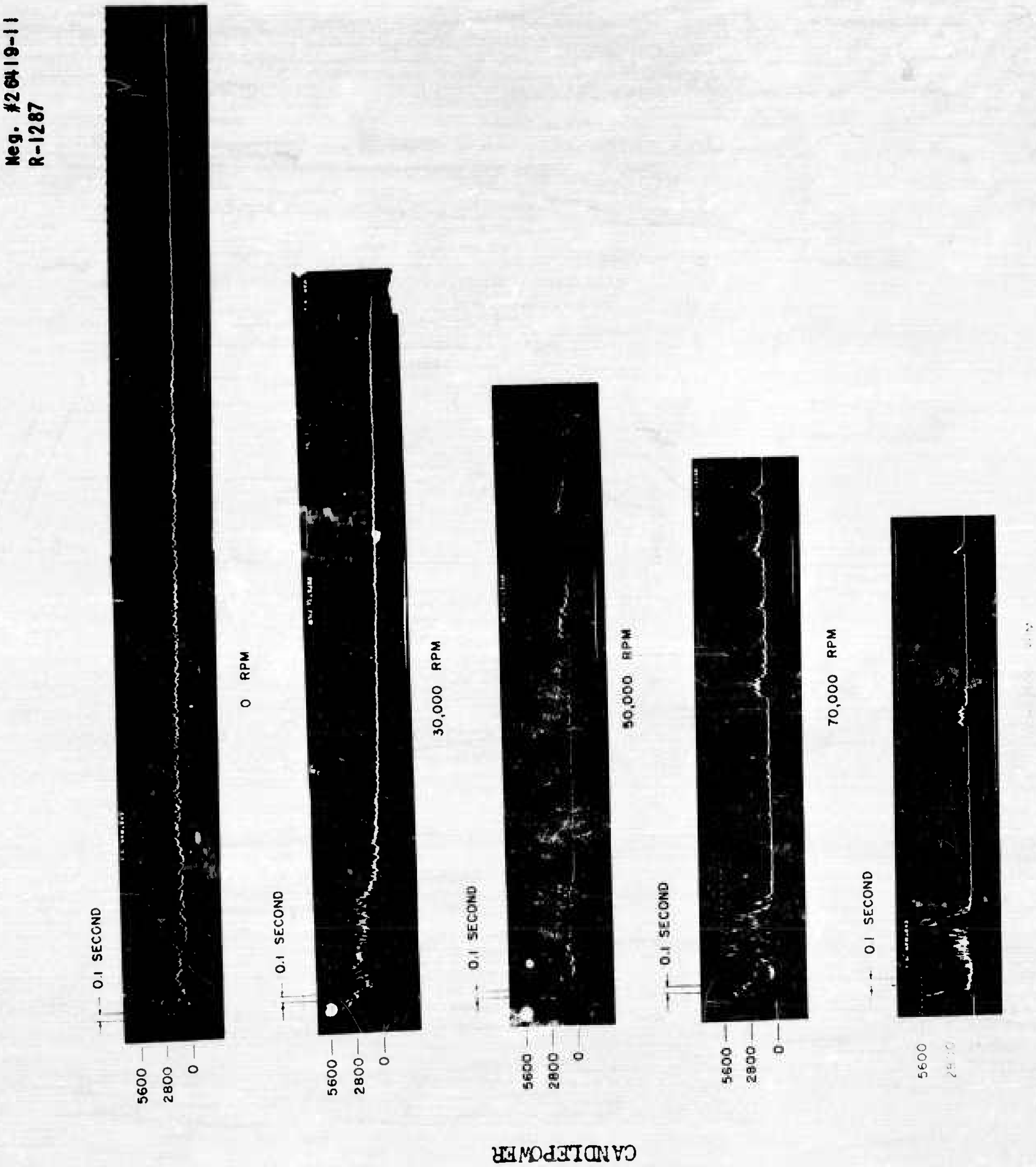

Figure 10. Effect of spin upon candlepower-time behavior of caliber .50 M17 tracer bullets

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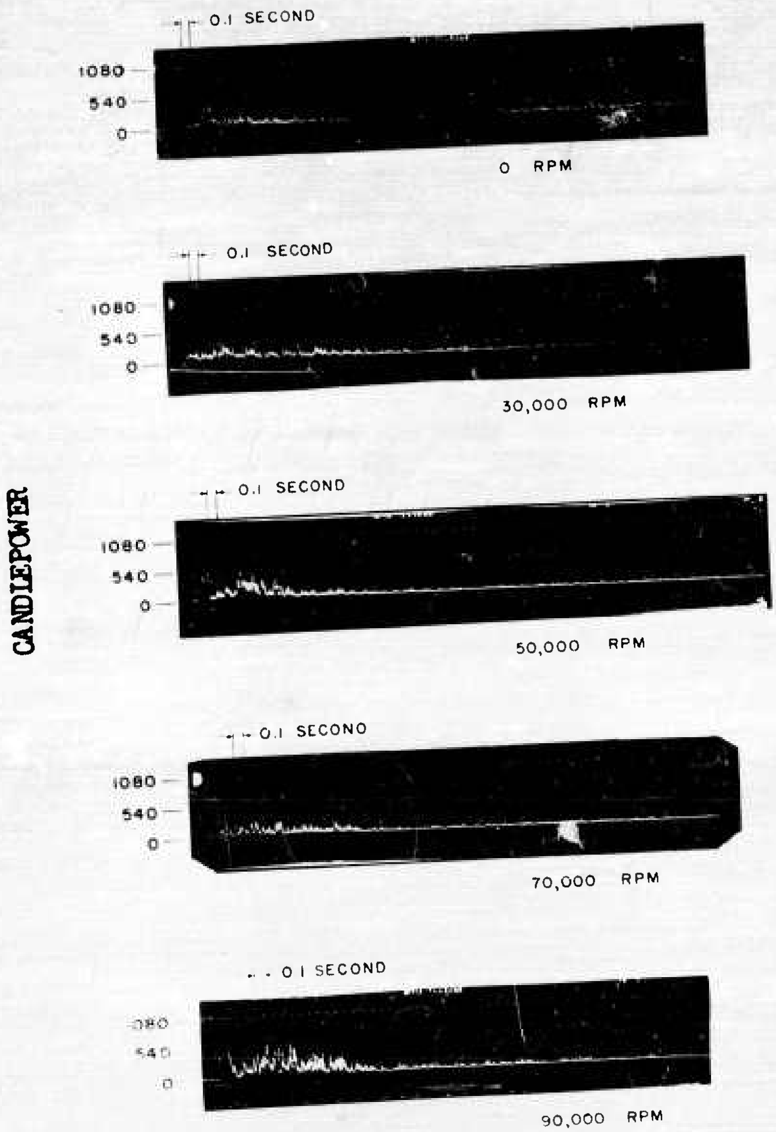

Figure 11. Effect of spin upon candlepower-time behavior of caliber .50 M20 APIT bullets

In conducting this study of flame intensity and trace duration it became evident that the igniters used appeared to affect the candlepower values to a marked degree. Caliber .50 M1 jackets were loaded with tracer compositions R-321 and R-256 so that, essentially, they were caliber .50 M17 bullets minus the igniter. Four lots of these were charged with four igniters. Ten grains each of igniters I-508, I-276, I-194, and of an igniter composed of lead dioxide, zirconium, and gum arabic were used. Statically and dynamically, at various rotational speeds up to and including 90,000 rpm, the differences in recorded candlepower in the four lots were large enough to merit further study (Figures 12 through 16).

In the work devoted to the study of the effect of igniters upon candlepower values it was noted that the smallest slag cavities were produced in those tracers charged with dim igniter I-194, and that the accompanying candlepower values were lower than for those bullets charged with the three bright igniters. The effectiveness of a bright igniter in increasing candlepower may be due to the initial hot flame produced, with an accompanying small amount of slag deposited at the surface of the cavity. Thus, greater egress is provided for the burning particles.

The effect of igniter compositions upon the duration of burning is usually slight. However, at all rotational speeds the experimental PbO_2-Zr igniter decreased burning times significantly below those for the other igniters.

The dimensions of the cavities produced in burned-out tracer bullets are dependent not only upon the type of tracer compositions used but also upon the igniter and the rotational speed. Figures 17, 18, and 19 illustrate the effect of spin upon the dimensions of these cavities. From the results of this phase of the work it appears that extremely small increments in slag cavity size will occur beyond 90,000 rpm.

In order to determine the point at which igniter intensity ends, caliber .50 M1 jackets were loaded with dummy tracers. Ten grains of each of the igniters mentioned were added. The duration and intensity of trace of these igniters are shown in Figure 20.

It was noted in this test that the ash left by the PbO_2-Zr igniter and by igniters I-508 and I-276, adhering to the jacket wall, was almost negligible. The ash left by the I-194, however, was voluminous and totally blocked the mouth of the bullet even at high rotational speeds.

From this evidence it may be assumed that the ash produced by the I-194 hinders the escape of the incandescent tracer particles, with a large proportion of them losing energy as they eject the I-194 ash and form the slag cavity shown in Figure 18. A com-

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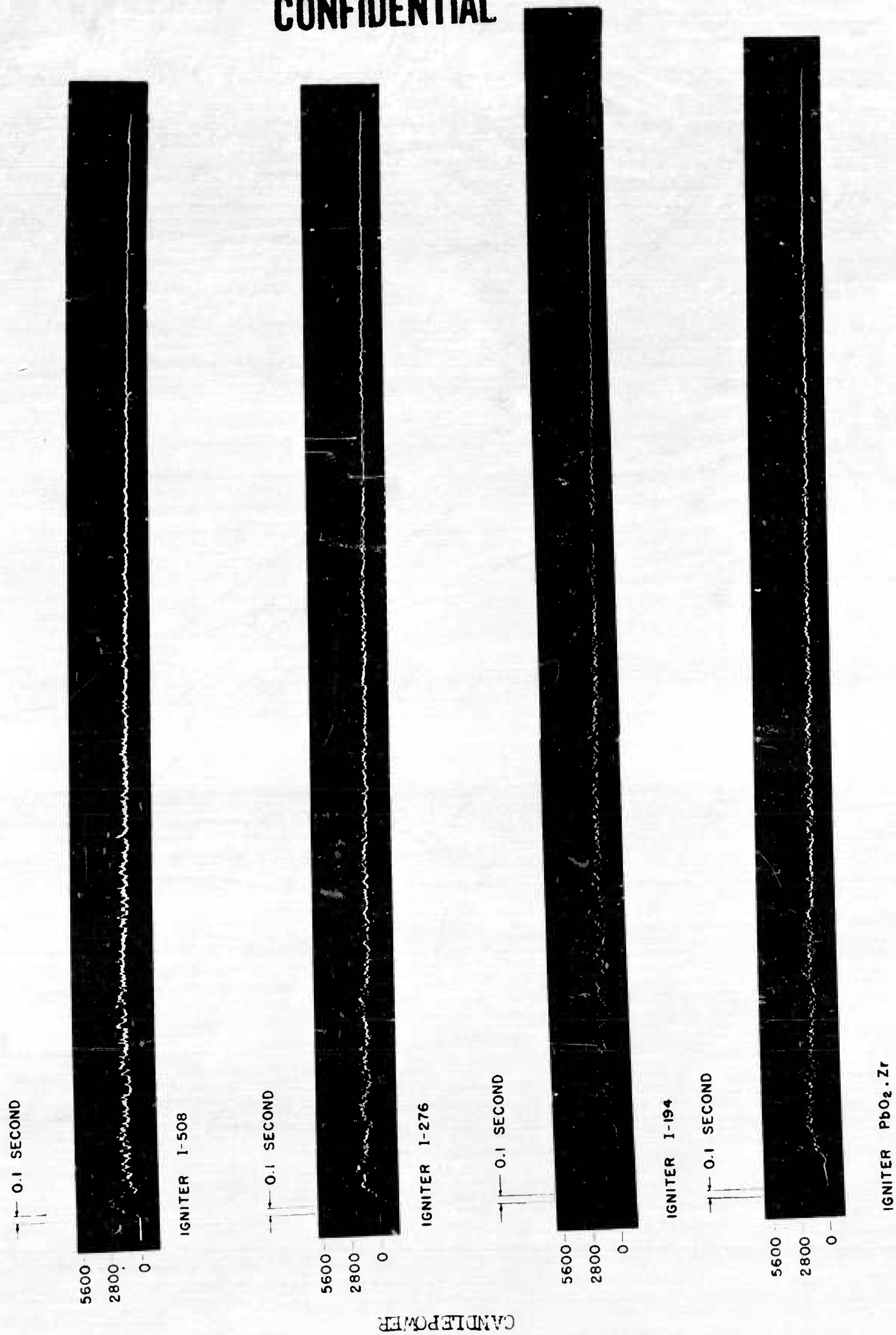

Figure 12. Effect of various igniters upon candlepower characteristics of modified caliber .50 M17 tracers at 0 rpm

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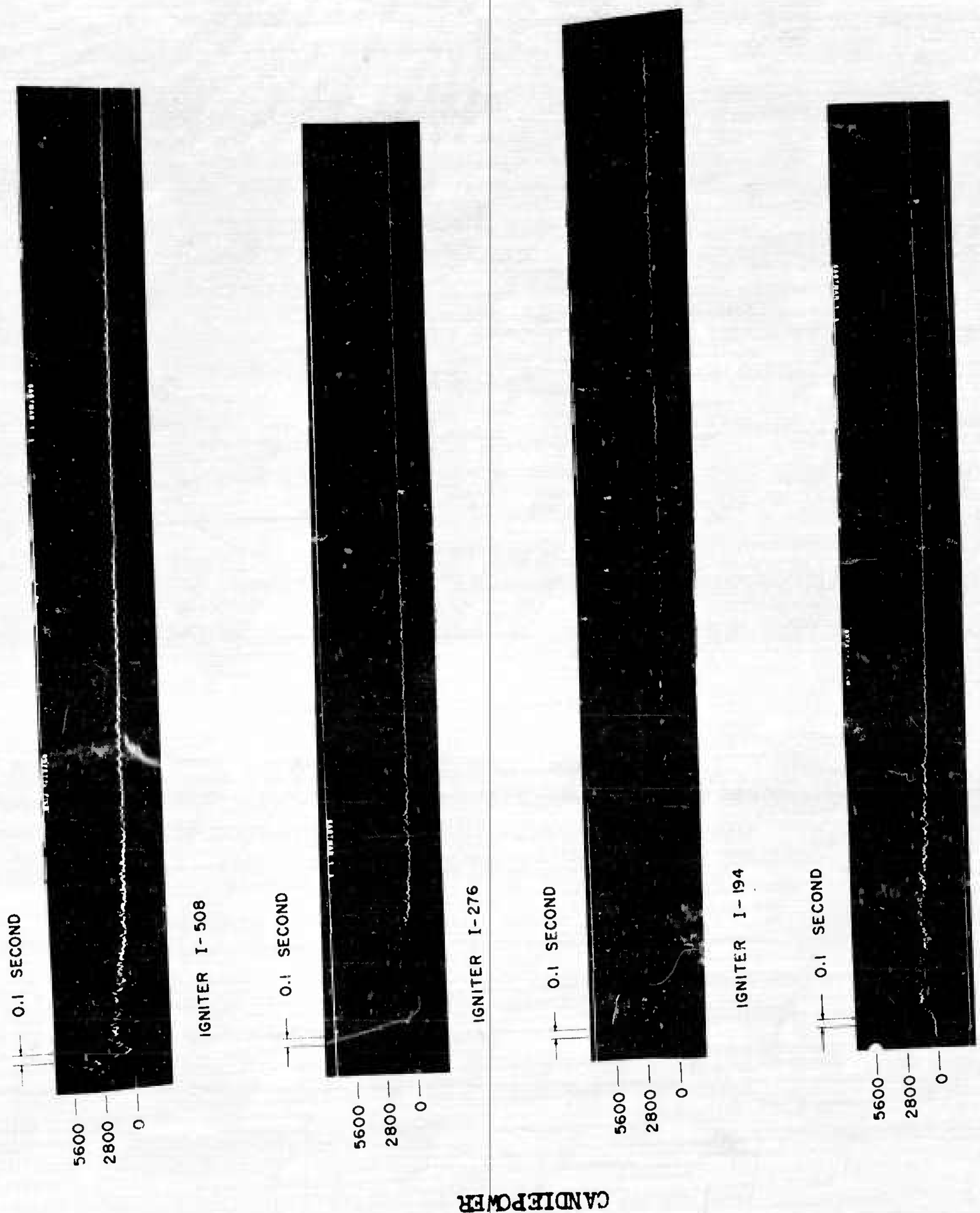

Figure 13. Effect of various igniters upon candlepower characteristics of modified caliber .50 M17 tracers at 30,000 rpm

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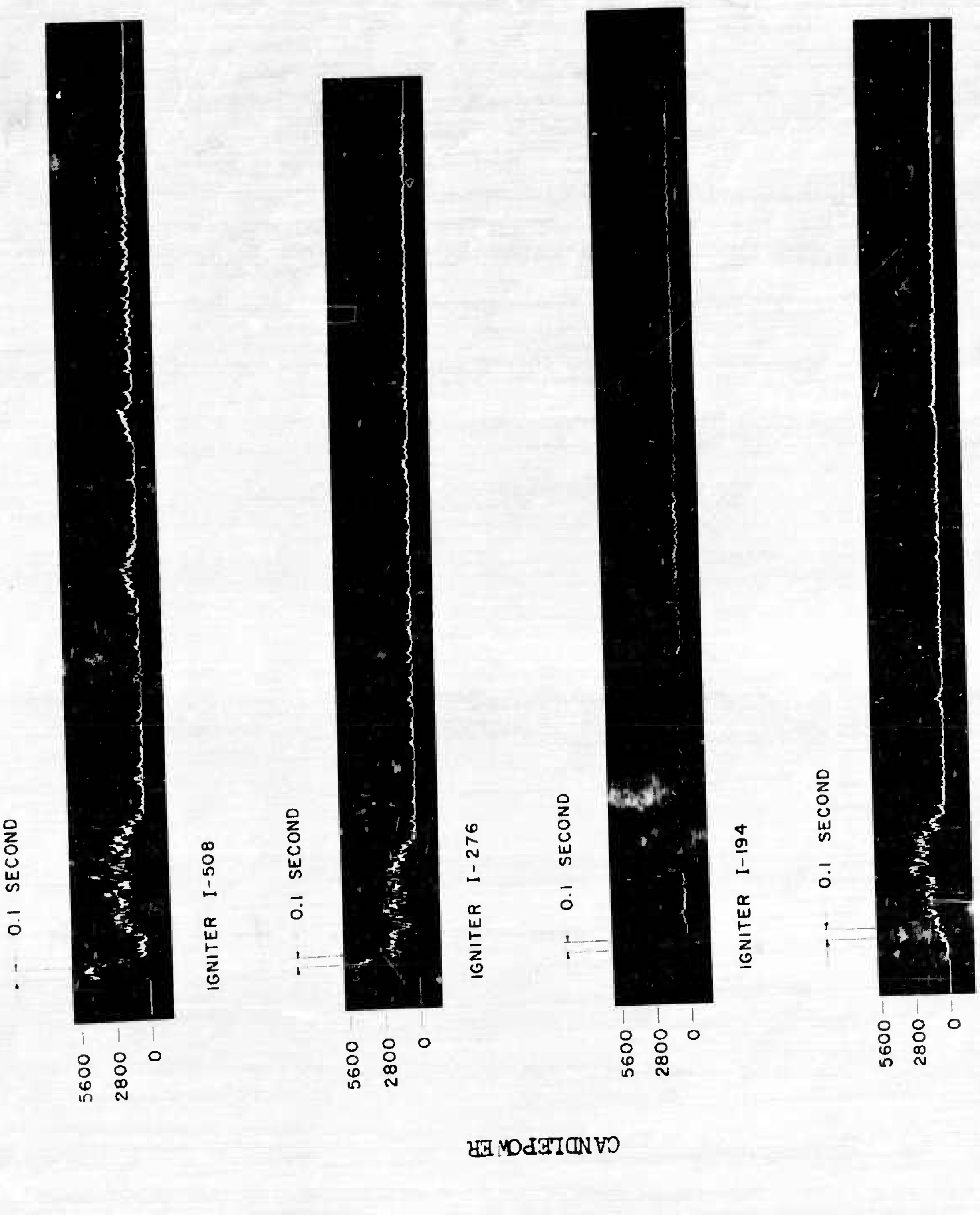

Figure 14. Effect of various igniters upon candlepower characteristics of modified caliber .50 M17 tracers at 50,000 rpm

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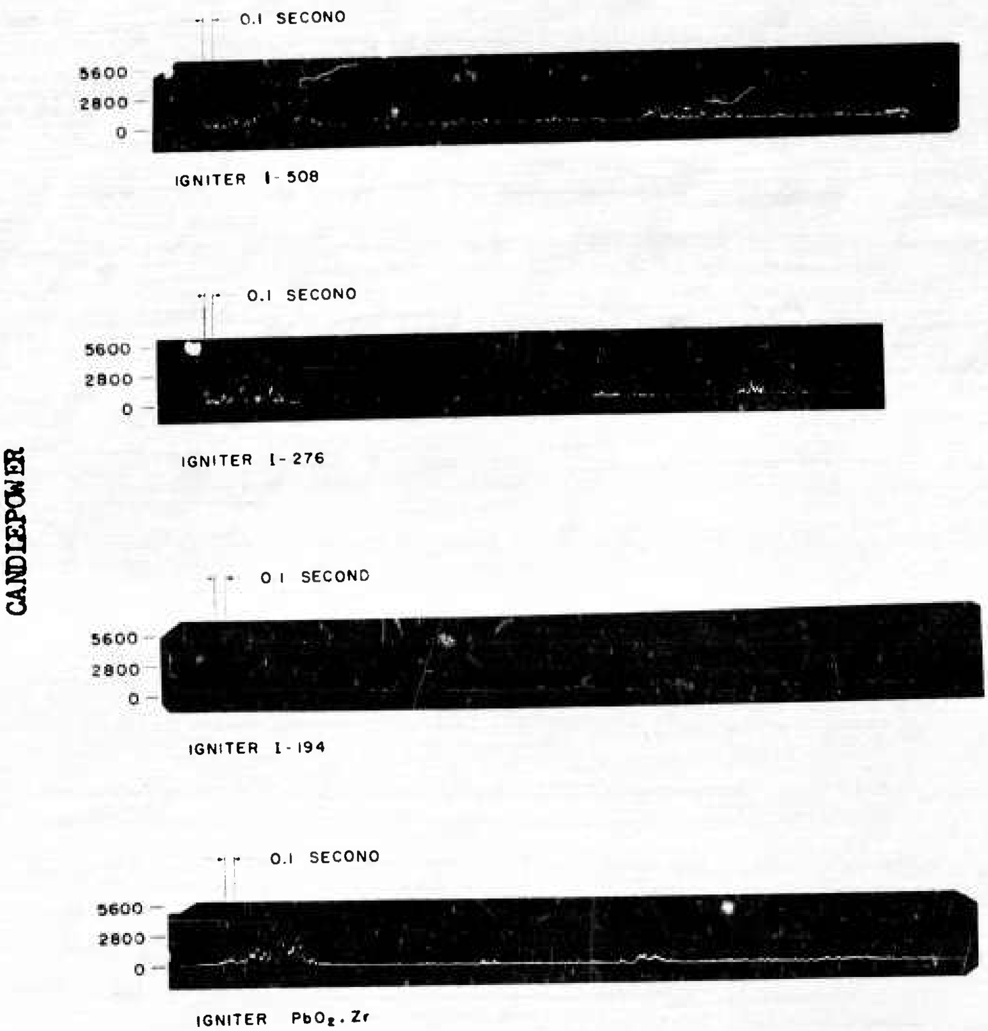

Figure 15. Effect of various igniters upon the candlepower characteristics of modified caliber .50 M17 tracers at 70,000 rpm

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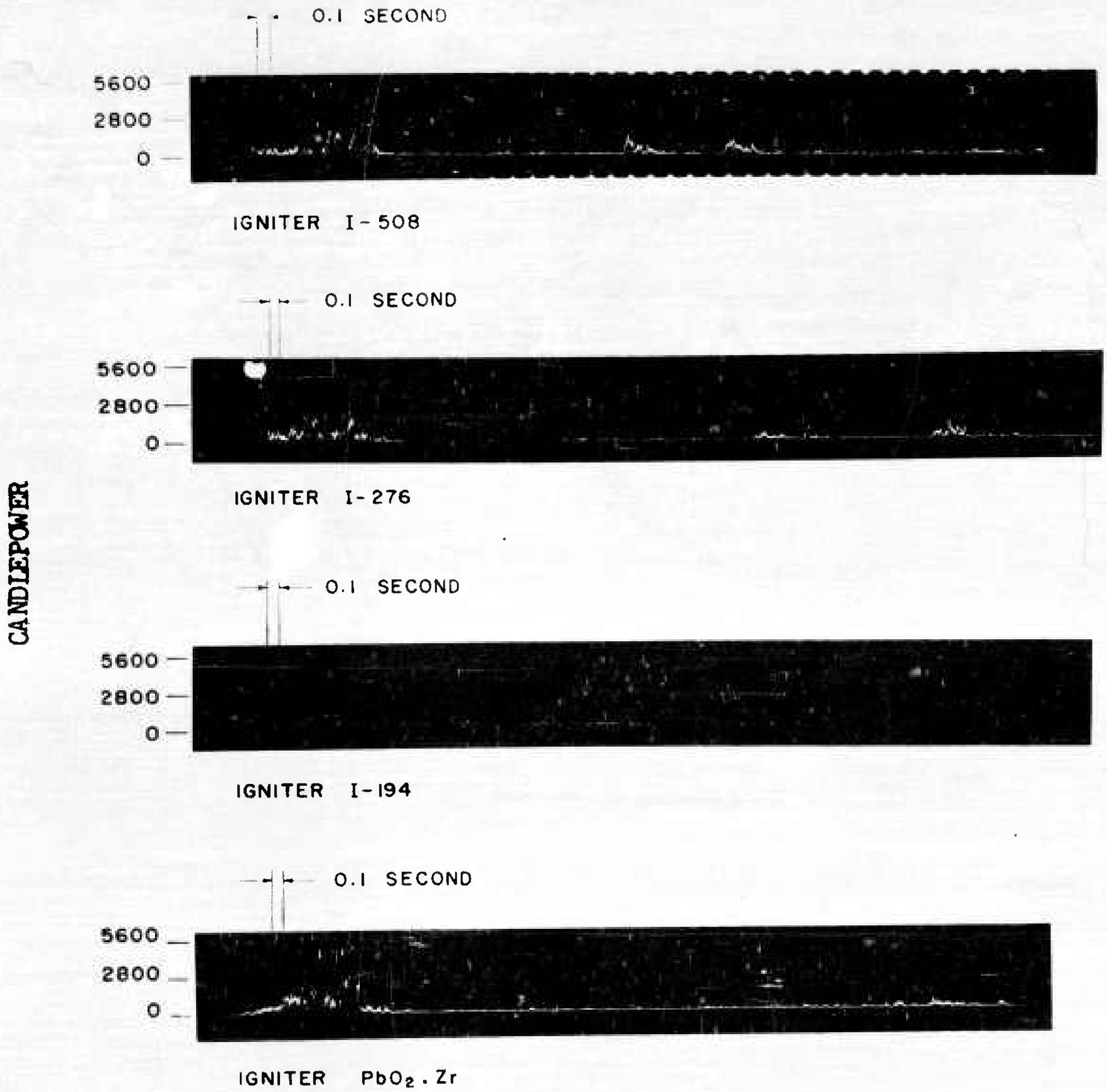

Figure 16. Effect of various igniters upon candlepower characteristics of modified caliber .50 M17 tracers at 90,000 rpm

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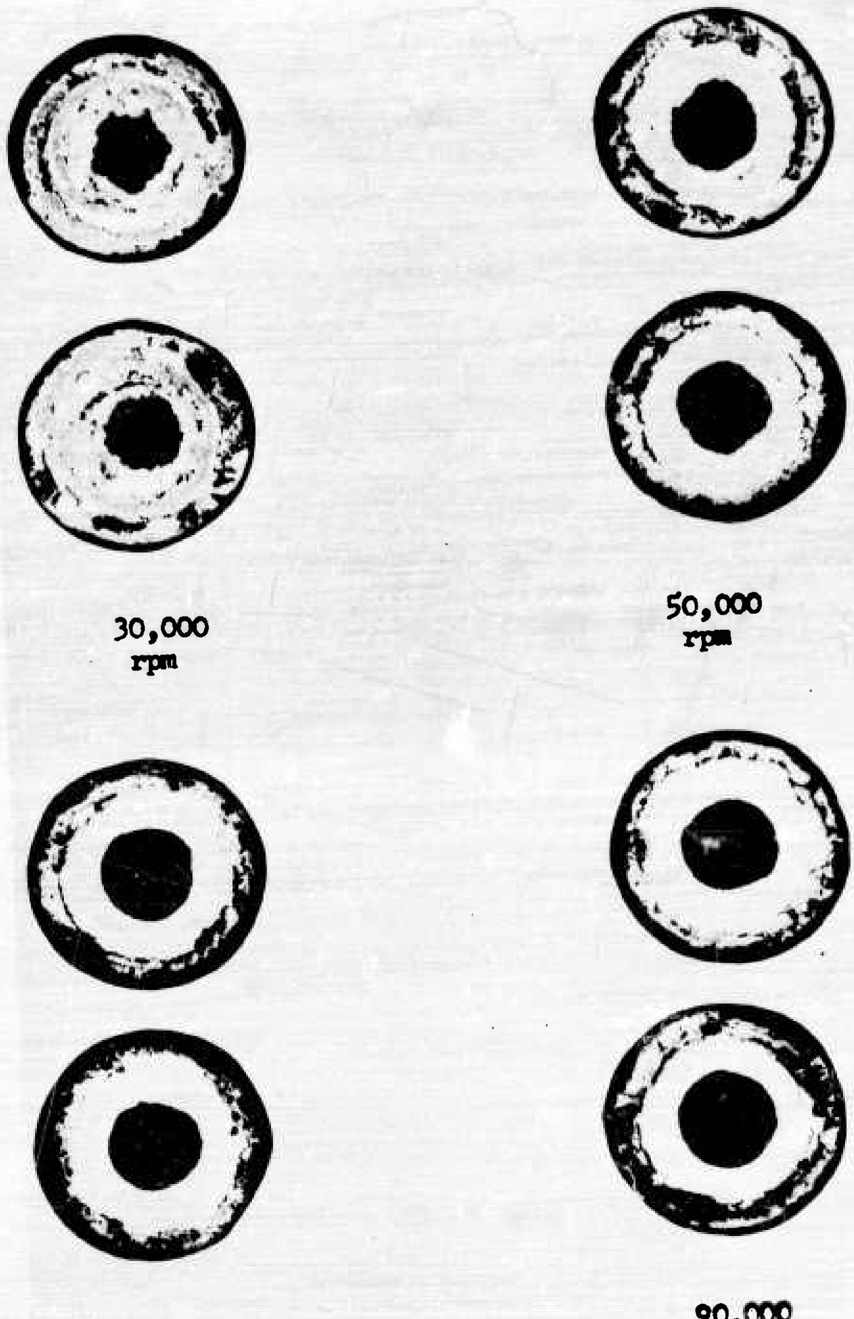

Figure 17. Effect of various rotational speeds upon slag characteristics of caliber .50 M1 tracer bullets

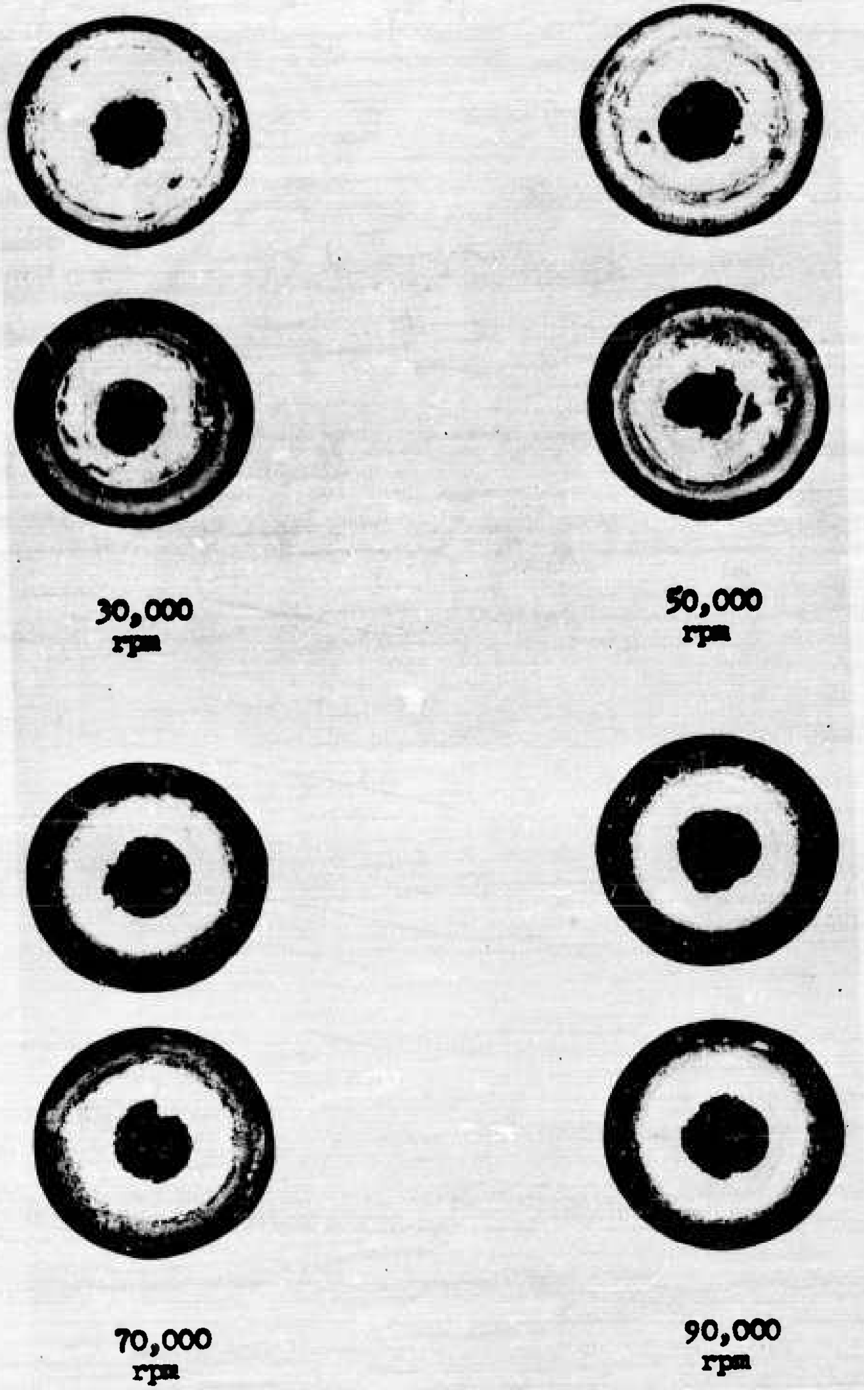

Figure 18. Effect of various rotational speeds upon slag characteristics of caliber .50 M10 tracer bullets

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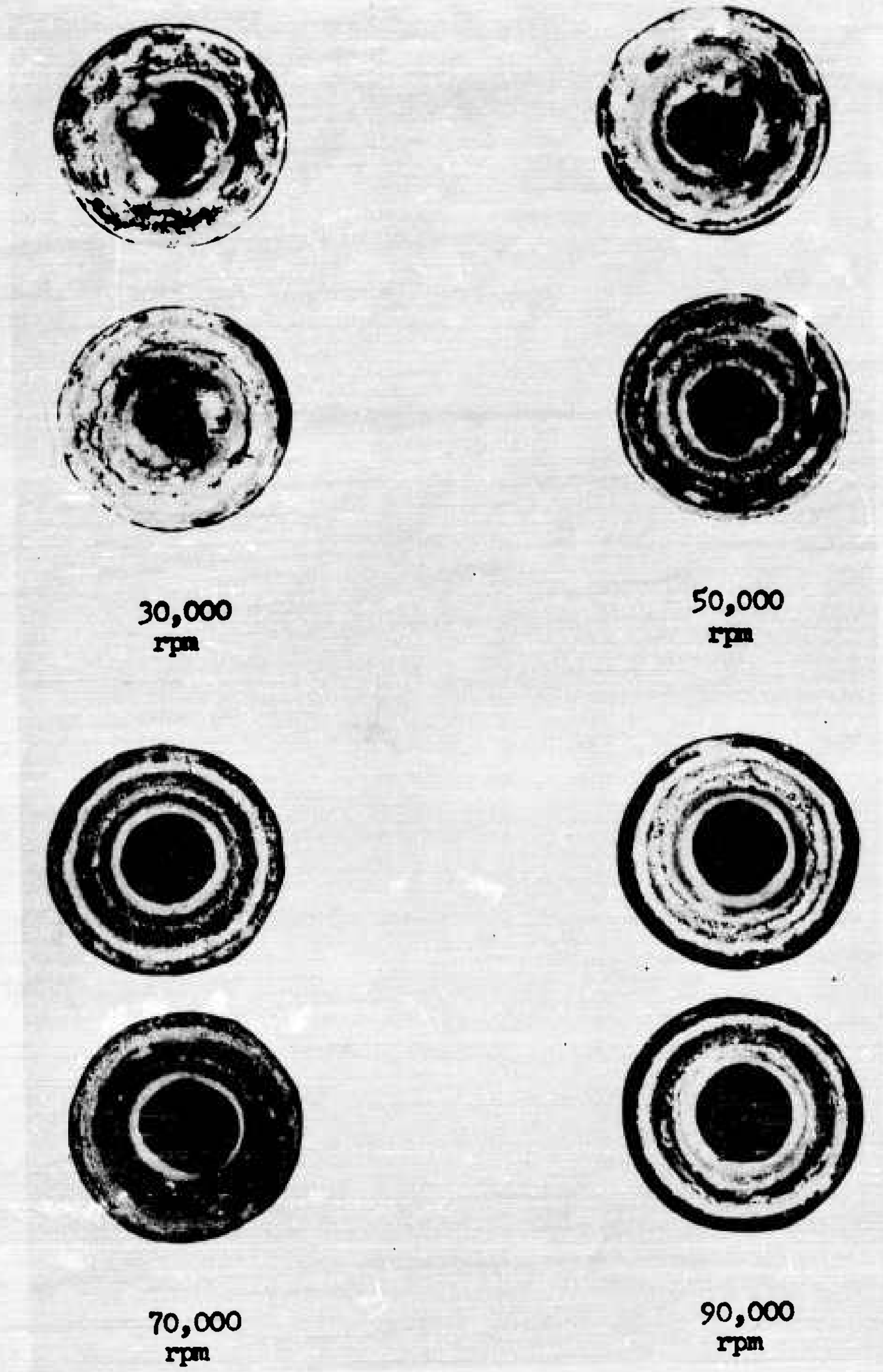

Figure 19. Effect of various rotational speeds upon slag characteristics of caliber .50 M17 tracer bullets

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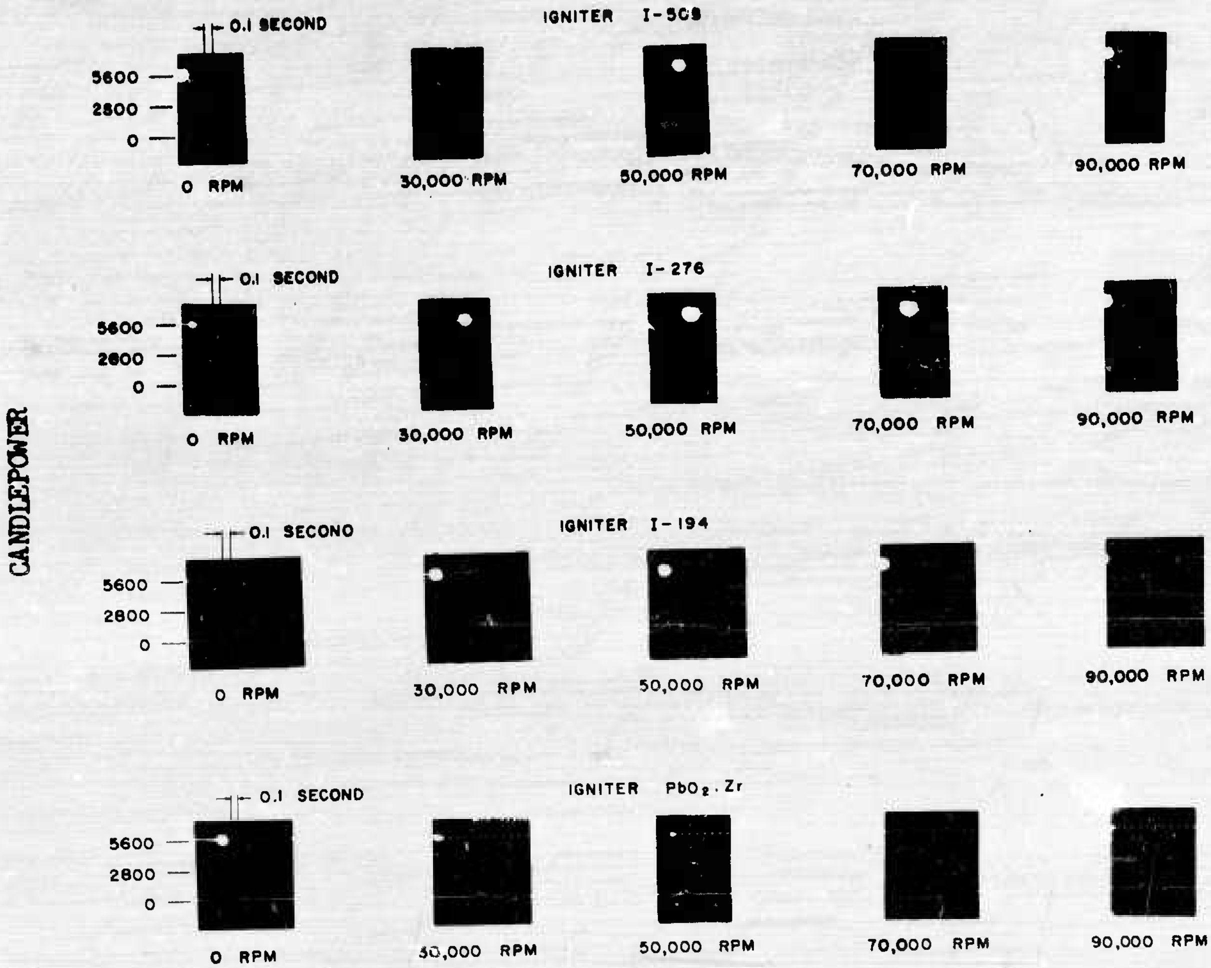

Figure 20. Effect of spin upon various igniters charged on dummy tracer mix in a caliber .50 M1 jacket

parison of the cavities formed in M1 and M10 tracers discloses an appreciable difference in diameter near the surface.

Since few tracer compositions were used in the standard ammunition tested, it was thought advisable to load these separately into caliber .50 M1 jackets and determine their individual characteristics, i. e., slag formation, light intensity, and trace duration at various angular speeds. Igniter I-276 was used. Dynamically, there was little variation in slag cavity size, but statically, R-257 produced a cavity which did not occur with the other tracer compositions. Intensities varied considerably. The graph of their time vs rpm characteristics is shown in Figure 21.

The data for tracer duration given in Table III were not obtained from film studies such as shown in Figures 7 through 16. Instead, the photoelectric cell was placed one foot from the spinner so that the beginning and end of the trace on film were prominent.

Table III. Candlepower-Time Data for Standard Small Arms Tracer Ammunition

Tracer	rpm	Duration (sec)	Total Intensity (candlepower-sec)
Cal .50 M1	0	13.0	5,500
	30,000	9.5	10,600
	50,000	8.2	9,820
	70,000	7.2	9,650
	90,000	6.4	5,300
M10	0	12.5	4,560
	30,000	9.5	4,670
	50,000	8.2	5,740
	70,000	7.2	6,320
	90,000	6.3	5,600
M17	0	13.7	12,000
	30,000	9.7	9,000
	50,000	8.3	5,200
	70,000	7.4	7,840
	90,000	6.5	4,000
M20 APIT	0	6.6	580
	30,000	6.3	460
	50,000	6.0	600
	70,000	5.7	490
	90,000	5.5	670
Cal .30 M25	0	3.8	700
	30,000	3.2	800
	50,000	2.5	800
	70,000	2.1	750
	90,000	1.95	800

Neg. #26419-22
R-1287

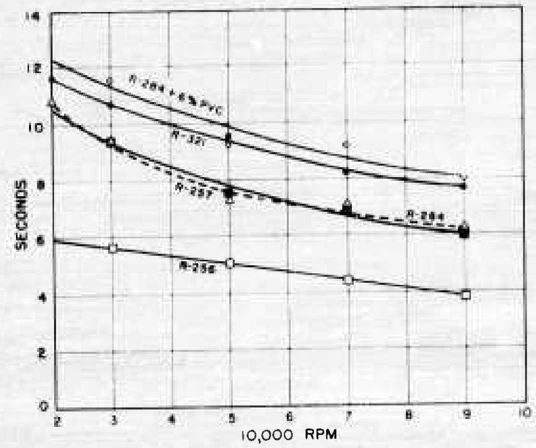

Figure 21. Effect on spin upon trace duration of various standard tracer compositions when loaded into caliber .50 MI jackets (Igniter I-276 used)

DISCUSSION OF RESULTS AT ABERDEEN PROVING GROUND

In order to determine whether the spinning of tracers in the laboratory gave data that were compatible with results obtained when they are fired in service, it was considered essential that they be timed under normal firing conditions.

Accordingly, a number of bullets from each lot tested in the laboratory was set aside and later assembled into cartridges. Approximately 25 to 30 of each type were shipped to Aberdeen Proving Ground and used in both day and night firing.

The visual results obtained in daylight firing were poor, the brightest trace, such as produced by the M17, being visible for less than 1000 yards to most of the observers. Some of them saw nothing. Similar difficulty was encountered with the other tracers fired, especially the caliber .30 M25 bullets. The latter were extremely

difficult to perceive when not silhouetted by the foliage. Only one of the five observers at the gun saw any trace. No trace was seen by any of the observers in the bunkers. The weather was clear and sunny. The results obtained in daylight firing appear to be typical of those normally encountered.

Night firing, however, was easily observed and timed by stop watches. The guns were slightly elevated so that the bullets would not strike the ground before they ended tracing. Observers were stationed at 1000, 1600, 2400, and 2500 yards for the caliber .50 tracers, and at 75, 125, 900, and 1000 yards for the caliber .30 M25 tracers.

For all tracers fired, close agreement on trace duration was reached. Table IV lists average duration and yardage. It will be noted in the table that the trace yardage for the M1 and M10 bullets is approximately the same as for the M17, yet they trace for 0.5 to 0.9 second less. This comparatively large disparity in trace duration, as compared to the small differences in yardage, can only be attributed to differences existing in muzzle velocities, differences in ballistic coefficients present before firing, and individual flight characteristics of each type of tracer. It should not be attributed to error, since it was believed by all concerned with the tests at Aberdeen Proving Ground that there was no difficulty encountered in night firing, and that the methods used were reproducible.

Table IV. Aberdeen Proving Ground Firing Data

Projectile	Gun	Avg Length of Trace (yd)	Avg Burning Time (sec)
Caliber .50			
M20	M2 heavy barrel	2300	5.5
M1	M2 heavy barrel	2700	5.5
M10	M2 heavy barrel	2650	5.1
M17	M2 heavy barrel	2650	6.0
Caliber .30			
M25	M1919A4	1150	1.8

Caliber	Type Tracer	Gun	Turns/ft in Barrel	Velocity* Linear (fps)	Velocity* Angular (rps)	rpm
.50	M1	M2 heavy barrel	12/15	2700	2166	129,600
.50	M10	M2 heavy barrel	12/15	2860	2288	137,280
.50	M17	M2 heavy barrel	12/15	2860	2288	137,280
.50	M20	M2 heavy barrel	12/15	2840	2328	139,680
.45	M26	Colt automatic	12/16	850	637	38,250
.30	M25	M1919A4	12/10	2600	3120	187,200

*Angular velocity = linear velocity times number of turns/ft in gun barrel.

It had been previously thought that the afterglow produced by burning tracers, which lingers momentarily after the tracer composition has been exhausted, would tend to contribute to an inaccurate tabulation of trace duration. This problem never arose. To all the observers there was a definite point at which afterflow was apparent, but its duration was insignificant, i. e., a fraction of a second, probably less than one tenth.

The use of reduced propellent charges and variable twist barrels in order to bring flight spin down to values that overlapped laboratory speeds had been considered, should the Aberdeen Proving Ground results fail to correlate satisfactorily with laboratory data. This, fortunately, was not nece y since the results obtained are considered in excellent agreement with laboratory data.

In comparing burning times of M1 and M10 tracers it will be noted in Table I that the first compression charge of an M1 consists of 40 grains of R-284, while the first compression charge of an M10 consists of an equal amount of R-256. Otherwise, the remainder of their tracer content is the same. As predicted by the graph (Figure 21), the M1 trace does last longer. The graph also indicates that an M17 will burn longer than an M1 because R-321 is slower burning than R-284.

DISCUSSION AND RECOMMENDATIONS

The results obtained at Aberdeen Proving Ground confirm the value of the laboratory bullet spinner as a useful tool in work with pyrotechnics. The decision to limit rotational speeds to 90,000 rpm should be applied to future work with tracer and igniter compositions. The steady and uniform decrease in burning times permits the prediction of data far beyond the calculated limits of the rotors that can be used in these experiments. The other safety measures taken appear adequate.

Three lots of caliber .50 M17 bullets were tested. They differed considerably in intensity and trace duration due to differences in tracer and igniter compositions used in their manufacture. This discrepancy of results with a standard tracer emphasizes the need for a fuller knowledge of the effect which igniter and tracer composi-tions have upon tracer behavior. The effect of igniter composition upon the candle-power values of tracers is great enough to justify further investigation.

From the correlation of laboratory and field results and from data compilations obtained in subsequent geometry of cavity studies (to be published), it is believed that the length of trace of any future tracer composition, when loaded into a projectile, will be predictable to a close approximation of the actual function.

From the work performed at Aberdeen Proving Ground and reports by other workera who are familiar with the behavior of tracers under bright daylight conditions, it appears to be generslly acknowledged that even the brightest tracers are difficult to observe for more than 1000 yards, which is less than 50 per cent of the requirement in specifications. During night firing, however, even the dimmest tracers used (based on comparative candlepower values) were readily and easily observed.

In view of the fact that the candlepower values, as noted on the films, are recorded with the projectile remaining at a constant distance from the photocell, while in flight the distance is constantly increasing, the method of determining the candlepower values may seem incongruous and inadequate, yet it continues to be the standard method, since it gives a comparative index of these candlepower values.

One of the inadequacies of tracers is that they are brightest in the initial stage of burning and become less intense in the final and longer stage. Thus, not only are their distances from the observer increasing but, in addition, their candlepower is decreasing.

Among the requirements for improving the candlepower of tracers is the development of compositions that have high candlepower values and produce a minimum of slag that will be retained by the bullet walls. Any methods used that will prevent slag retention will aid considerably in increasing candlepower.

APPENDIX A

The standard lamp is a 500-watt GE Mazda projection bulb rated at 1769 candlepower by the National Bureau of Standards under the following specific conditions.

"The luminous intensity was measured by means of a calibrated physical photometer. The physical photometer is calibrated at periodic intervals against the basic lamp standards. This photometer, consisting of a thermopile and luminosity filter, is a modified form of the one described in NBS J Research, Vol 27, p 217, RP1415, Sep 1941.

"The lamp was standardized while burning base down. The orientation was such that the plane containing the two lines etched on opposite sides of the bulb was parallel to the photometer axis, the line having the etched circle being turned away from the photometer. A diaphragm having an opening 2.5 centimeters high and 15 centimeters wide, centered with respect to the filament and located 7 centimeters from the center of the socket, was placed between the lamp and the photometer. The photometric distance was 1.25 meters. With the voltage held constant at the designated value. readings were taken of current and luminous intensity."

Using the formula $\frac{cp}{D^2} = \text{ft-c}$

where

$$cp = \text{candlepower}$$
$$\text{ft-c} = \text{foot-candle}$$
$$D = \text{distance (ft)}$$

this standard lamp was positioned behind the opening specified above, while the photoelectric cell used in this work was placed 1.25 meters from the center of the light source. Although this bulb was standardized in the absence of any other light, it was found that under moderate daylight conditions and prevailing laboratory illumination only a slight increase of foot-candle reading resulted, i. e., less than 3 per cent.

A Weston photometer was used to calibrate the oscilloscope deflections. The photoelectric cell was then placed at various specific distances from the light source. The amount of deflection of the oscilloscope beam on the screen was recorded in inches and foot-candles and served as a standard for all candlepower work done with pyrotechnics.

APPENDIX B

The formula used in computing bursting strength of rotors will be found in "Strength of Materials," Timoshenko, Vol 2, p 247.

$$\sigma_{t_{max}} = \frac{\gamma v^2}{g}\left(\frac{3+\omega}{4}\right)\left(1 + \frac{1-\omega}{3+\omega}\propto^2\right)$$

where

$$v^2 = R^2\omega^2 = \frac{D^2\omega^2}{4}$$

and $\omega = \frac{2\pi n}{60}$

$$\therefore v^2 = \frac{\pi^2 D^2 n^2}{3600}$$

$$\sigma_{t_{max}} = \frac{\gamma\pi^2 n^2 D^2}{g\ 3600}\left(\frac{3+u}{4}\right)\left(1 + \frac{1-u}{3+u}\left[\frac{d}{D}\right]^2\right) \quad \text{where } d \to 0$$

$\sigma_{t_{max}}$ = maximum tensile stress, tangent to inner rim = lb/in.^{2}

γ = specific weight of material = lb/in.^{3} = 0.283 for steel

g = gravitational constant = 12 x 32.2 in./sec^2

R = outer radius of disk in inches = $\frac{D}{2}$

r = inner radius of disk in inches = $\frac{d}{2}$

n = rotative speed of disk in rev/min

ω = rotative speed of disk in radians/sec

v = peripheral speed of disk in in./sec

$\propto = \frac{d}{D}$

u = Poisson's ratio = 0.30 for steel.

Substituting in above equation $\left(\begin{array}{l}\frac{d}{D} = 0 \\ u = 0.30\end{array}\right)$ and solving for D

$$D = \frac{120}{\pi n}\sqrt{\frac{g\sigma_{t_{max}}}{3.3\gamma}}$$

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